are so small when they reach inhabited coasts that they can be detected only by tide-gages. The height of the waves vary from 84 feet, actual measurement (210 feet reported in another case) to less than an inch. The period of the waves as well as their height depends on the size and shape of the bay affected as long ago pointed out by Omori. Where deep water occurs right up to the shore line the waves have but little effect and may even escape detection while the same wave may be destructive on an adjacent coast that is bounded by shallow water. It has been found that for several Japanese bays and some others that the periods of the waves are constant for each bay whatever the source and are the fundamental periods of the bay.[3] The periods as observed vary from 5 to 30 or more minutes. The length of the waves sometimes reach 200 miles.

During the eleven years that seismographs have been in operation at the Volcano Observatory several earthquakes that were followed by tidal waves have been recorded. The one on September 7, 1918, in the Kamchatka region, 3,200 miles away, caused a tidal wave that did some minor damage in Hilo. The computed velocity of this wave was nearly 8 miles per minute. Another on April 9, 1919, the origin of which appears to have been southwest of Hawaii, affected a large part of the Pacific Ocean. There is considerable shallow water between Hawaii and the origin, and the velocity of the sea wave to Honolulu was 4.7 miles per minute while the velocity to San Francisco was 5.9 miles per minute. The mean depth of the ocean to the last-named port is much greater than to Hawaii. The small tidal wave that followed the Chilean earthquake of November 11, 1922, was predicted by T. A. Jaggar, jr., nearly 10 hours in advance. The velocity of the waves to Hilo in this case was 7.5 miles per minute. On April 13, 1923, a very small record of an earthquake was obtained about 5:17 a. m. and at 12:40 p. m. a small tidal wave occurred at Hilo. The record was too feeble to determine the distance, but from the time of the tidal wave the order of magnitude of the distance was computed to be near 3,000 miles. Later reports from other stations make the origin near Kamchatka, about 3,200 miles away.

It is usually impossible to make positive predictions of tidal waves from the records from one station, for even if the distance and general direction is known the distribution of land is such that there is nearly always a doubt as to whether the break occurred on land or under the ocean. As the seismographs are inspected rather infrequently a quake might be recorded and the tidal wave occur before it was ascertained that there had been a quake unless a device is arranged whereby a bell is made to ring whenever a quake is being recorded.

The fact that the transit time of the first preliminary waves through the earth in minutes and seconds is very nearly equal to the transit time of the seismic sea waves in hours and minutes affords a quick means of predicting the approximate time of arrival of the waves. A table is on file at this station showing the distance to most of the earthquake regions in the Pacific and the transit time of the sea waves from each region. The times were obtained either from known quakes that caused tidal waves or computed from the above rule.

[3] *Jour. Col. Sci. Imp. Univ. Tokyo*, vol. 24, 1908; also Davison, *Manual of Seismology*, p. 98.

C. E. P. BROOKS ON VARIATIONS IN THE LEVEL OF THE CENTRAL AFRICAN LAKES, VICTORIA AND ALBERT[1]

551.481 (916)

By ALFRED J. HENRY

[Weather Bureau, Washington, March 16, 1924]

The opening paragraph of this memoir contains the key to the discussion, viz, the remarkable way that the level of these lakes changes in sympathy with changes in the spottedness of the sun.

The evidence is presented both graphically by means of curves and also by the statistical method using the method of correlation coefficients, both of which seem to fully support the thesis.

Lake Victoria is situated between the meridians of 31° 40′ and 35° 00′ east of Greenwich and 0° 20′ north and 3° 00′ south latitude. The Equator passes over the northern part of the lake. Lake Albert is situated about 150 miles northwest of Victoria and is much smaller. The area of Victoria is 26,000 square miles; soundings made within 10 to 12 miles of shore give depths varying from 50 to 200 feet. In the bays and creeks the water is shallow; little is known of the depths in mid lake.

As one might expect, the numerical data utilized are neither plentiful nor of high accuracy. The precipitation data are derived from 10 stations scattered along the shore of the lake and elsewhere in Uganda. The early part of the record consists of a smaller number of rainfall records and is consequently less reliable.

The determination of the lake level rests upon daily gagings made at the eastern extremity of Kavirondo gulf, a deep indentation of the northeastern shore. The author gives only the single highest and lowest of these readings for each month. I have calculated therefrom the mean monthly lake level by the formula $\frac{\text{max.}+\text{min.}}{2}$ and present the monthly values in Table 1.

TABLE 1.—*Mean monthly level, Lake Victoria (in inches and tenths)*

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
1896	*26.0*	*23.0*	*22.5*	*22.0*	*23.0*	*22.0*	*19.5*	*18.5*	*14.5*	*11.0*	*15.5*	*17.5*	*19.6*
1897	17.5	18.5	19.5	22.5	22.0	24.5	24.0	-----	-----	-----	-----	-----	-----
1898	-----	-----	-----	-----	25.0	22.0	23.0	22.0	22.5	22.0	22.0	22.5	-----
1899	20.0	18.5	18.0	18.0	21.5	22.0	15.5	5.5	4.5	−1.0	−1.5	2.0	3.6
1900	1.5	0.0	0.5	1.0	5.0	3.5	−1.5	−3.0	−2.0	−8.5	−13.0	−5.5	−1.8
1901	−4.0	−4.5	−2.5	11.5	20.0	18.5	11.0	4.0	−1.0	−3.5	−4.5	−7.5	3.1
1902	−10.0	−10.5	−10.5	−11.0	−6.0	−8.5	11.5	−10.5	−13.5	−11.0	−10.0	−3.5	−9.7
1903	−1.5	0.5	4.5	4.0	*8.5*	*20.0*	*20.5*	*19.5*	18.5	20.5	*19.5*	*21.0*	12.9
1904	16.0	19.5	18.0	22.0	27.5	21.5	19.5	22.0	10.5	12.5	12.5	15.0	18.0
1905	16.5	19.5	19.5	19.0	20.0	19.0	15.0	13.0	7.5	8.5	8.5	14.0	15.0
1906	15.0	16.5	21.5	35.0	41.0	41.5	27.0	35.5	32.5	25.5	27.0	26.5	28.7
1907	25.0	24.0	20.5	22.0	29.0	29.0	25.0	20.5	14.5	14.5	13.0	13.5	20.9
1908	12.5	9.5	10.0	8.5	12.0	12.0	11.5	10.5	8.5	8.5	10.5	10.0	10.3
1909	10.0	11.0	12.5	11.0	13.5	11.5	10.0	4.0	4.0	4.5	−1.5	0.5	7.6
1910	0.5	−2.0	−1.0	1.5	*11.0*	*5.5*	*2.0*	*1.5*	*0.5*	*−3.5*	*−4.5*	*0.0*	*1.0*
1911	−5.0	−8.5	−10.0	−5.5	0.0	2.0	−2.5	−6.0	−9.5	−13.0	−15.5	−14.5	−7.3
1912	−14.5	−11.0	−14.5	−11.5	−4.0	−4.0	−8.0	−10.0	−10.5	−13.5	−13.0	−12.0	−10.5
1913	−12.5	−9.0	−6.5	−6.5	4.0	8.0	7.5	0.5	−3.0	−6.0	−4.0	−4.0	−2.6
1914	−7.5	−6.5	−5.0	−2.0	1.5	2.0	0.0	−0.5	−2.0	−4.0	0.0	1.5	−1.9
1915	0.0	−2.5	3.0	4.5	6.5	11.5	13.0	2.5	1.5	1.5	2.0	4.5	4.0
1916	6.0	9.5	8.0	13.0	17.5	23.5	20.5	16.5	16.5	18.5	17.5	16.0	15.3
1917	20.0	23.0	23.0	30.5	40.5	*43.5*	*38.5*	*36.0*	*37.0*	*39.5*	*43.5*	*40.5*	*34.6*
1918	40.5	36.5	33.0	32.0	35.0	33.0	28.5	22.5	20.0	17.0	14.5	15.5	27.3
1919	9.0	−2.0	−0.5	3.0	14.5	18.5	13.5	7.0	8.5	6.5	6.0	7.0	7.6
1920	6.5	3.5	0.5	6.5	10.0	10.5	4.5	1.5	−0.5	−2.5	−5.0	−4.0	2.6
1921	0.5	1.5	0.0	−1.0	−1.5	−1.5	−2.5	−6.5	−9.0	−10.5	−11.5	−13.0	−4.6
1922	−16.0	−14.0	−18.5	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----

[1] *Geographical Memoirs No. 20*, Air Ministry, Meteorological Office, London, 1923.

The gage readings are fairly consistent among themselves except in the single instance of July, 1906, the minimum reading for that month appearing to be at least 10 inches too low. The monthly mean for June of the same year is 41.5 inches, July 27 inches, and August 35.5 inches. Neglecting the rain which fell upon the surface of the lake, 2.30 inches, there remains a shrinkage of 14.5 inches in level over an area of 26.000 square miles in a single month. This amount is so greatly in excess of any recorded measurements of evaporation that it seems to be quite improbable. If the reading was as reported it must have been due to some unusual local condition that did not affect the level of the lake generally.

The rainfall departures from the normal are presented in Table 2 below, together with the monthly means or normals in the bottom line.

TABLE 2.—*Average rainfall over Uganda (departures from monthly and annual normals).*

	January	February	March	April	May	June	July	August	September	October	November	December	Year
	Inches	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*
1895	−0.26	−0.29	+0.76	+7.09	+5.50	−1.95	−0.55	−0.22	−0.25	−0.13	+4.74	+0.32	+14.76
1896	+0.12	−2.27	−0.25	−1.54	−2.93	−0.93	−1.09	+1.21	−1.49	0.00	+5.55	−0.38	− 4.00
1897	−0.58	+0.28	−0.67	+0.52	+0.34	+0.84	+0.24	+3.34	+4.22	+2.77	+0.18	−1.28	+10.20
1898	+1.00	−1.57	−1.08	−2.24	−3.97	+2.11	+0.07	+0.16	+0.70	−0.06	+0.36	−1.08	− 5.60
1899	−2.00	−0.12	−2.55	−0.52	+0.07	−2.35	−1.77	−2.35	−2.09	−0.94	−0.95	−0.13	−15.70
1900	+0.92	+2.69	+1.30	−0.95	−3.45	−1.21	−1.76	+0.27	−0.42	−1.07	+2.44	+5.05	+ 3.81
1901	−0.69	+2.57	+0.88	+0.33	−0.74	−2.06	−0.44	−2.02	−1.65	−1.25	−1.17	−1.68	− 7.82
1902	−0.97	+0.02	−1.03	−1.21	+0.71	−1.11	−2.18	+1.52	−1.32	+0.80	+1.18	+0.36	− 3.23
1903	+2.27	−1.50	−0.11	+0.60	−0.59	+4.30	+0.65	−1.46	+1.72	+0.98	−2.64	−0.40	+ 3.82
1904	+0.84	+0.49	+1.89	−1.33	+0.61	−0.41	−0.89	+1.05	+0.36	+1.30	+2.29	+2.52	+ 8.72
1905	+0.92	−1.08	+3.80	−2.36	−0.22	−0.84	+0.79	+0.03	+1.21	+2.41	+3.04	+2.55	+10.25
1906	−0.95	+2.55	+2.62	+2.03	−0.58	+1.55	−0.13	+0.99	−0.03	+0.96	−2.44	−0.88	+ 5.09
1907	+0.07	+1.27	−3.05	+3.87	+3.05	−0.15	−0.07	−0.97	−0.15	+0.87	+1.96	+0.36	+ 7.06
1908	−1.12	+0.12	−2.39	+1.00	+1.52	+0.51	−0.08	+0.93	−1.86	+0.30	−0.66	−0.22	− 1.95
1909	+0.39	−1.77	+1.10	+3.32	−1.56	−1.17	−0.16	+1.82	+1.75	−0.58	−1.13	+4.06	+ 6.07
1910	+1.40	−0.31	+0.95	+0.87	+2.00	−0.33	+1.83	+0.59	−0.82	+0.89	−0.26	+0.44	+ 7.25
1911	−0.24	−1.82	+1.95	+0.04	+1.54	−0.91	−0.88	−0.81	−2.02	−0.40	−3.19	−1.79	− 8.53
1912	+0.69	+0.19	+0.27	+1.42	−0.20	+0.41	+0.27	+1.19	+0.49	−0.90	−0.06	+0.56	+ 4.33
1913	−0.82	+0.64	−0.13	−0.11	+0.02	−0.51	−0.28	−2.29	−1.97	−0.51	−1.87	−1.49	− 9.32
1914	−0.29	−0.63	−0.14	−2.57	−0.59	+0.66	+0.78	+0.11	+1.50	−0.45	+1.60	−1.34	− 1.36
1915	−0.68	−0.88	+0.94	−1.59	−0.52	+0.60	−0.80	−1.91	+0.57	−0.71	−0.73	+0.85	− 4.86
1916	−0.55	+1.13	−0.57	−0.06	−0.82	+0.68	−0.63	0.00	+2.07	−0.59	−1.16	+0.06	− 0.44
1917	+0.65	+1.71	−2.88	+1.98	+0.58	+0.30	−1.42	+0.79	+0.43	+0.64	−2.62	−2.05	− 1.89
1918	−0.30	−1.77	−1.72	−0.63	−0.37	−0.59	−0.51	−1.03	−0.89	−1.55	−1.79	−1.03	−12.18
1919	−1.04	+2.54	+0.45	−2.22	−0.55	−0.97	−1.63	−0.53	−0.89	−0.82	−0.12	−0.86	− 6.64
1920	−0.52	−1.72	+0.22	−0.68	+0.26	+0.58	+0.24	−1.16	−1.41	−0.34	+0.04	−0.07	− 4.56
1921	−0.65	−0.73	−2.44	−2.93	−0.59	−0.25	−1.85	−0.26	−0.21	−0.46	0.00	−0.32	−10.69
1922	−0.98	−0.07	−2.25										
Mean	2.17	3.06	4.60	7.35	5.82	3.58	2.48	3.80	4.60	4.76	5.16	3.33	50.71

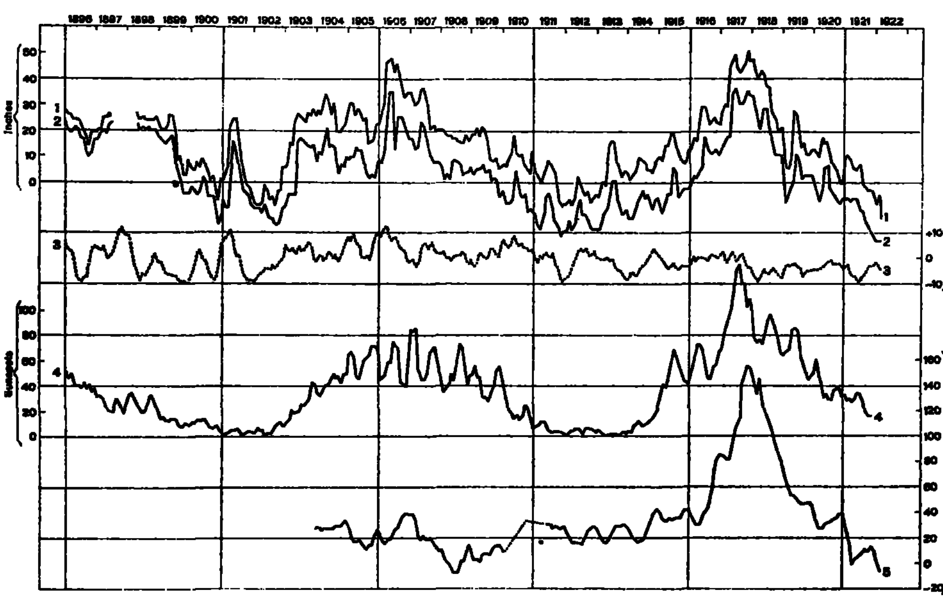

FIG. 1.—Curves 1 and 2, monthly maximum and minimum lake levels in inches above or below zero level. Curve 3 rainfall in Uganda, deviations from normal summed in overlapping periods of six months. Curve 4, monthly sun-spot numbers. Curve 5, mean level of Lake Albert in inches above zero level

The climate of the two lake basins considered is tropical with the usual two rainy seasons corresponding approximately with the times of vernal and autumnal equinoxes; the autumnal rainy season being delayed somewhat, the maximum monthly amount falling in November. It is to be remembered, however, that some rain falls in each month of the year and that the minimum monthly amount is 2.17 inches (normal for January).

This figure shows the author's graphical method of showing the parallel values of lake level, rainfall, and sun spots. In making the rainfall curve the, sums of the monthly deviations in overlapping periods of six months have been used. The sun-spot curve has been produced through the use of Wolfer's relative numbers as published in Meteorologische Zeitschrift, smoothed by taking the mean of each three successive months, allocated to the middle one.

In addition to direct correlations partial correlation coefficients were calculated showing the relation between lake levels and rainfall, the sun spots being constant, and between lake levels and sun spots, rainfall being constant. In Table 3 below the suffix "1" indicates lake level, "2" rainfall, and "3" sun spots. The usual notation is employed, 12.3 meaning correlation coefficient between lake level and rainfall corrected for sun spots and so on. In the third line, coefficients deduced from annual means have been added for comparison.

TABLE 3.—*Correlation coefficients between lake levels, rainfall, and sun spots*

	r_{12}	r_{13}	r_{23}	$r_{12 \cdot 3}$	$r_{13 \cdot 2}$
1899–1921	+0.26	+0.74	+0.12	+0.25	+0.72
1902–1921	+.29	+.81	+.08	+.39	+.82
1902–1921	+.39	+.87	+.12	+.59	+.90

Annual figures.

From the foregoing-named data the author concludes as follows:

> From Table 5 (Table 3 of this abstract) it appears that while the level of Lake Victoria depends to some extent upon the rainfall, the relation to sun-spot numbers is much more close, the corrected coefficient reaching +0.82 for the period 1902–1921, even when monthly figures are considered, in spite of the fact that no lag is allowed for, while the annual means which to some extent compensate for the lag and also tend to smooth out irregularities, give a corrected coefficient as high as +0.90. These are remarkable figures, and indicate a very close connection between the lake levels and the radiation from the sun. Such a connection can only be through evaporation (p. 342).

And again: (p. 343):

> After allowing for these factors [rainfall and run-off] enough agreement remains to show that evaporation is responsible for by far the greatest loss of water in Uganda, and also that (other things being equal) the evaporation is nearly but not quite proportional to the rainfall.
>
> * * * * *
>
> The chief factor in the amount of evaporation, however, is not rainfall but solar conditions. The researches of W. Köppen and others have established beyond doubt that there is a close connection between sun spots and tropical temperature, the latter being 1.1° F. higher at spot minimum than at spot maximum. It is reasonable to conclude that the higher the temperature the greater the evaporation; hence at spot minimum evaporation will be increased and the level of the lake will fall, while at spot maximum evaporation will be decreased and the level of the lake will rise. The relationship, as we have seen, is so intimate that it gives correlation coefficients of between 0.8 and 0.9.

In affirming the above conclusions our author seemingly has set aside one of the fundamental laws of hydrology, viz, that the quantity of water in any drainage system is directly due to the rain or snow that falls within its borders plus that which is impounded in depressions, lakes, ponds, etc., plus any flow of ground water that may occur; minus, losses due to seepage, evaporation, and by outflow to another system.

While our knowledge of all of these factors may be incomplete, or completely lacking we are not therefore justified in assuming as a fact, something which might probably be true, but has not as yet been proved to be true.

It is perhaps unfortunate that the author did not have more extended data on the synchronous variations of sun spots and lake levels. The period used, 1896–1922, contains but 2 epochs of maximum sun spots and say 3 epochs of minimum spots, although the precise epoch of 1923 has not yet been fixed. In all he had but 5 events whereas he should have had at least 6 times that number.

A simple comparison of the two variables, sun spots and lake levels will now be made.

Sun spot maxima, 2 epochs, 1906 and 1917.—High lake levels prevailed in both years but the high water in the first named was clearly due to increased rainfall as shown in Table 2.

Sun spot minima, 2 epochs, 1901 and 1913.—The mean lake level in 1901 was 3.1 inches; it should be classed as a year of moderately low water. The water level in 1913 was −2.6 inches, a year of low water. Low lake levels also prevailed in 1902, −9.7; 1910, 0.9; 1911, −7.3; 1912, −10.3; 1914, −1.9; 1921, −4.6 inches.

It is quite apparent from the above that low lake levels for the period, 1896–1922, tend to group themselves around years of few sun spots, although not necessarily around the epoch of minimum spots of each cycle. We will return to this subject later.

It seems to be worth while to examine in greater detail relation between rainfall and lake levels. Using the monthly normals as found in Table 4, I have plotted the month-to-month accumulated differences and present the curves so formed in Figure 2.

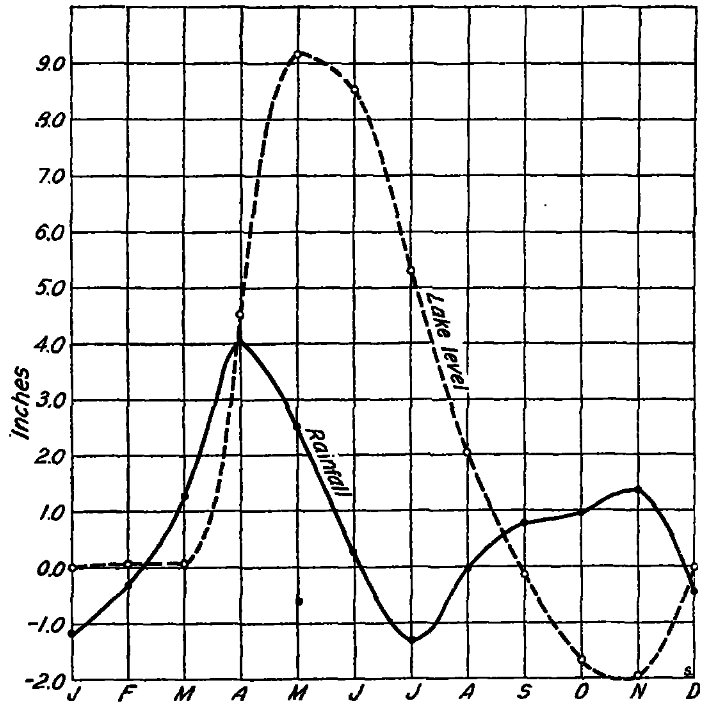

FIG. 2.—Month-to-month accumulated differences of normal rainfall and normal lake level

TABLE 4.—*Monthly normals of rainfall and lake levels*

	January	February	March	April	May	June	July	August	September	October	November	December	Year
Rainfall:													
Normal	2.17	3.06	4.60	7.35	5.82	3.58	2.48	3.80	4.60	4.76	5.16	3.33	50.71
Sum for six months ending with the named month	23.82	23.08	23.08	25.67	26.33	26.58	26.89	27.63	27.63	25.04	24.38	24.13	25.35
Height[1] of Lake Victoria:													
Normal monthly, maximum	12.7	13.2	13.2	17.2	21.9	21.2	18.0	14.7	12.4	11.0	10.7	12.7	14.9
Normal monthly, minimum	0.5	−0.6	−0.5	2.8	8.7	10.4	6.5	3.4	1.3	0.1	−0.5	0.4	2.7
One-half (max. +min.)	6.6	6.3	6.3	10.0	15.3	15.8	12.3	9.1	6.9	5.5	5.1	6.5	8.8
Height[2] of Lake Albert (mean monthly)	44.1	39.9	35.0	33.6	33.4	34.5	34.9	36.1	39.7	42.7	46.0	46.0	39.4

[1] In inches above the zero level of 3,276.15 feet above m. s. l.
[2] In inches above the zero level of 2,028.1 feet above m. s. l

From the curves of the above figure it will be seen that there is close agreement between rainfall and lake level and that there is very little lag between them. The rainfall increases from January to April; the lake rises from March to May, cresting just one month after the rain maximum. The rainfall begins to diminish in May and likewise the level of the lake begins to descend in congruence therewith. The decrease of rainfall from the April maximum of 7.35 inches to the July minimum of 2.48 inches is, of course, 4.87 inches.

The months of greatest evaporation are July, August, and September. The fall in the level of the lake which is very pronounced in June and July is apparently checked in the last-named month and while it continues to fall until November, in spite of the second rainy season, a rise sets in, in that month, that culminates in December, when it has reached the secondary maximum of the year. This secondary maximum is considerably less than the primary by reason of the great evaporation loss during the months, July to October, and the diminished rainfall of the autumnal as compared with vernal rainy season.

The curves of Figure 2 show the following relation, viz, that with a rising lake and small evaporation, as must naturally be the case in the rainy season, the ratio of normal precipitation to normal lake level is about as 1 to 2; thus the accumulated increase in normal precipitation, February to April, is 4.29 inches (from Table 4), the normal rise in lake level March to May, allowing a month's lag is 8.7 inches. With falling lake and increasing evaporation as the dry season approaches, the ratio diminishes slightly, thus decrease in normal precipitation April to July, 4.87 inches; decrease in lake level May to August 7.2 inches. The decrease in the ratio obviously is due to the greater evaporation in the one season as compared with the other.

Throughout this discussion the outflow of the lake over Ripon Falls has been considered as constant. This is not, however, strictly true, as Professor Marvin has orally pointed out to the writer. By reason of high lake levels at certain seasons of the year the discharge at those seasons must be greater than at intermediate and low stages. No quantitative data thereon are available but the increased discharge should be considered as a factor in reducing the ratio, rainfall to lake level, with a falling lake.

It is a pity that with the apparently well-equipped meteorological station of Entebbe, Uganda, on the northwest shore of the lake, observations should not have been made that would have served to compute the possibilities of evaporation from the lake surface.

It is known of course, that evaporation depends not on the relative humidity, but upon the vapor tension due to the temperature of the water surface, and the vapor tension of the layer of air directly in contact with that surface. If this difference is large evaporation will be rapid, while evaporation will decrease as the two values of vapor tension approach each other. The records of the Entebbe station contain readings of the wet and dry bulb thermometers made three times daily but no records of water temperatures.

We may get some idea of the possibilities of evaporation by considering the effect of a definite change in the air temperature of the layer in immediate contact with the lake surface. The mean maximum air temperature in the thermometer shelter at Entebbe for June, July, August, and September is $77.5+77.0+77.3+79.0\div$ by 4 or 77.7 F. For the sake of argument let us assume a drop in temperature for these four months to 76 F. or 1.7 less than the 10-year mean.

The maximum pressure of aqueous vapor over water at—

	Inch
Temperature 77.7 F. is	0. 9581
Temperature 76 F. it is	0. 9056
Diff	0. 0525

With no change in water temperature the evaporation would be diminished almost 5 per cent by a drop in air temperature of 1.7 F. Since the assumed drop in temperature in the above example is greater than that postulated by the author it is difficult to see on what grounds a large evaporation is to be expected at times of spot maximum or minimum.

Curiously enough the author seems not to have gone to the trouble of ascertaining whether or not the air temperature at Entebbe, the only meteorological station on the lake, had varied in consonance with the sunspot theory. I have computed the 10-year mean of the annual temperature maximum and minimum, respectively, for Entebbe. The means are as follows: Mean maximum 78.9 F.; mean minimum 62.8 F. For 1917 the year of spot maximum the temperature at Entebbe was *above* the 10-year mean as follows: Mean maximum +0.8 F., mean minimum +0.4 or directly the opposite of that called for by theory. The temperature in the spot minimum year of 1913 was also above the 10-year mean.

We have not yet touched upon by far the most interesting problem presented in the memoir, viz, whence came the water that filled the lake to overflowing in 1917? We feel reasonably sure that it did not come as a result of diminished evaporation in the drainage basin of the lake, although a small portion may have had its origin in that manner. I have plotted the course of the lake for the three years, 1916–1918 in order to bring out some points that might otherwise be overlooked. The result is shown in Figure 3.

From this point on in the discussion the lake itself is considered as a better index of the precipitation that occurred in the drainage basin than the rain gages themselves. During 1916 the level of the lake increased 10 inches, from 6 inches in January to 16 inches in December, in spite of the fact that the rainfall deviations for the year were negative by nearly half an inch. The small drop in level during the dry months of June and July, and perhaps also the decreased evaporation of July, August, and September may partially account for the increase in level.

The average shrinkage in lake level for the dry season computed for 25 seasons is 8.8 inches. The shrinkage during 1916 was but 7 inches, or nearly 2 inches less than the average. Possibly this amount should be charged against diminished evaporation. I do not know.

Not only was the high level attained in December, 1916, maintained but an additional increase in level of 4 inches was gained during January, 1917, and thus the lake *inherited from 1916* a gain of 14 inches of water spread over 26,000 square miles.

The deviation of the 1916 rainfall from the normal, see Table 2, was −0.44 inch, small and negative to be sure, but this is a case where the figures do not tell all of the story. The detailed records of the Entebbe station show that for March, 1916, there were 11 rainy days, April, 15 rainy days, May, 11 rainy days, June, 15 rainy days, a total of 52 of which 32 were consecutive, as follows: March 7, April 9, May 4, and June, 12. This means that the sequence in which the rain falls is of more importance than the actual amounts. In June 4.81 inches fell on consecutive dates from the 18th until the 30th; the greatest amount in any 24 hours during this period was but 1.10 inch and the least 0.06 inch, but the effect is clearly apparent in Figure 3 and in the numerical values of Table 1. Evaporation is not only greatly reduced by continuous cloudy rainy weather, but the run-off is much greater because the vegetative cover of the basin becomes thoroughly wetted and sheds water so much the quicker and with less loss from interception and absorption.

The rainfall record for 1917 is much similar, the annual deviation from normal being −1.89 inches. Here again annual figures are not significant; one should consult the monthly deviations as shown in Table 2. These show that rainfall was decidedly below normal in March, moderately below in July, and decidedly below in both November and December. The detailed record of rainfall made at Entebbe shows that March had but 3 rainy days, April had 23, of which 18 *were consecutive*; May had 19, 13 *consecutive*.

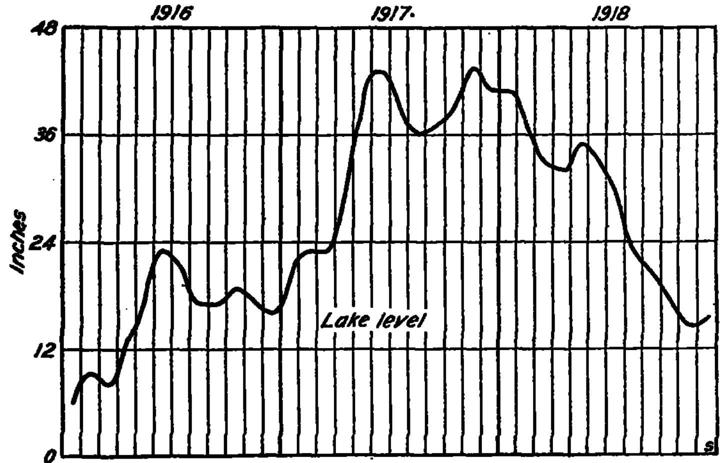

FIG. 3.—Lake level, in inches, for 1916–1918 (Lake Victoria)

June had 7, scattered throughout the month, and July had but 0.02 inch for the entire month; August 15 rainy days, 5 *consecutive;* September, 12, 6 *consecutive;* October, 10, 5 *consecutive;* November and December had few rainy days and they were scattered throughout the month.

By following the curve of Figure 3 it will be seen that the lake rose practically uninterruptedly from January to June in perfect congruence with the rainfall. The lack of rain in July, only 0.02 inch is manifest in the drop in the curve for July and August. More rain, favorably distributed sent the lake up to a second maximum in November equal to the first maximum in June.

A period of deficient rainfall set in in November, 1917, continuing uninterruptedly for 14 months, then followed 2 months of normal rains and again a deficient period, this time lasting without a break for 11 months. The lake level was, of course, falling during these periods of deficient rains and reached in March, 1922, the lowest point ever recorded, viz. 18.5 inches below its normal level. The lake level will of course rise in response to a return of the rainfall to normal. The high water of 1917 might be explained in one or more ways as independent of the rainfall; first, the discharge over Ripon Falls might have been greatly retarded through channel obstructions during 1916 and 1917, or, second, prevailing southerly winds during these same years may have driven the water to the northern end of the lake—the neck of the bottle; but it is preferred to believe that the response of the lake to the natural rainfall and run-off has been such as might have been expected and that it is unnecessary to have recourse to changes in solar radiation to explain the variations in level as described.

Through the courtesy of Mr. R. Z. Kirkpatrick, chief hydrographer of the Panama Canal, the editor has been supplied with monthly values of observed evaporation from a 4-foot pan floating in Lake Gatun, Canal Zone, Panama, an artificial body of water formed by damming the Chagres River. The lake has an area of 164 square miles. The 11-year mean evaporation from this lake is roughly 60 inches, of which 44 per cent occurs during the dry season—January to April, inclusive, and the remaining 56 per cent occurs during the remaining months of the year. During the year of sun-spot minimum, 1913, evaporation from the lake was 108 per cent of the 11-year average; during the year of spot maximum, 1917, evaporation was 102 per cent of the average. The least evaporation was 87 per cent in 1921 and the greatest 109 per cent in 1918. There is here no suggestion of a sun-spot influence upon evaporation.

DISCUSSION BY C. E. P. BROOKS [2]

I am glad to see this review, although I do not entirely agree with your remarks.

The rainfall for Uganda employed in the original memoir were the best I could do at the time, and I was very glad to receive the more extensive figures given by Mr. Phillips, director, Cairo Hydrological Service (Nature, London, 113:440).

I have already had an opportunity of considering the *effect of this modification,* in an unpublished paper on the subject written at the request of the Uganda Literary and Scientific Society. I have unfortunately no spare copies of this paper, but may quote the following expression of my revised views:

> Since the level of the lake shows so close an agreement with the number of sun spots, the latter must have a dominating influence on one or both of the prime factors which influence the lake level, namely, rainfall and evaporation. A comparison of the average rainfall over the lake plateau, according to Mr. Phillips, with the sun spot numbers shows that the rainfall is generally high when sun spots are increasing and low when sun spots are decreasing. The change in the average sun spot number from one period of 12 months (July to June) to the succeeding 12 months shows a good agreement with the rainfall amounts * * * the correlation coefficient being +0.64, which indicates good but by no means remarkable agreement. The correlation coefficient between plateau rainfall and the change in the level of Lake Victoria is +0.91, indicating a very close agreement. Since the level of the lake depends on the rainfall and the rainfall depends on sun spots, it is evident that the level of the lake would show agreement with sun spots even if there were no other factor. To measure this agreement between lake level and sun spots through rainfall we multiply together the two correlation coefficients given above, i. e., 0.64×0.91=0.58, and this would be the correlation coefficient between lake level and the sun spots if no other factor than rainfall had to be taken into account. But the connection between lake level and sun spots is much closer than this; it gives a correlation coefficient of +0.87. Therefore some other factor in the lake le besides rainfall must be closely connected with sun spots, and * * * this factor must be evaporation.

[2] A copy of the foregoing having been furnished Doctor Brooks, he makes the following comment.